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The IRGen Infrared Data Base Modeler

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ABSTRACT

IRGen is a modeling system which creates three-dimensional IR data bases for real-time simulation of thermal IR sensors. Starting from a visual data base, IRGen computes the temperature and radiance of every data base surface with a user-specified thermal environment. The predicted gray shade of each surface is then computed from the user-specified sensor characteristics. IRGen is based on first-principles models of heat transport and heat flux sources, and it accurately simulates the variations of IR imagery with time of day and with changing environmental conditions.

The starting point for creating an IRGen data base is a visual faceted data base, in which every facet has been labeled with a material code. This code is an index into a material data base which contains surface and bulk thermal properties for the material. IRGen uses the material properties to compute the surface temperature at the specified time of day. IRGen also supports image generator features such as texturing and smooth shading, which greatly enhance image realism.

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Imaging IR Sensors

Imaging IR sensors (also called FLIR's), generate high-resolution video-rate images. The images displayed by an IR sensor are radiance maps of the scene viewed by the sensor. In the thermal (mid-IR and long-IR) bands, the radiance from a surface contains both emitted and reflected radiance. The emitted term depends on the surface temperature, and thus most IR images show a scene.

Since an imaging IR sensor displays the radiance from the scene, the appearance of a scene varies significantly with time of day, and with environmental conditions. Contrast reversals are frequently observed over the diurnal temperature cycle.

Atmospheric attenuation is a significant factor in the thermal IR bands. Attenuation varies dramatically with local meteorological factors such as humidity, fog, and rain.

Imaging IR Sensors

- **High-resolution image, updated at video rates.
The image is a radiance map of the scene.**
- **Total scene radiance includes both emitted and reflected radiance**
- **The appearance of the scene can vary significantly with time of day**
- **Atmospheric attenuation is significant and can vary dramatically with local meteorological conditions**

IR Simulation Methodologies

Several modeling methodologies have been used to generate data bases or images for IR sensor simulation. The simplest technique complements the intensity of the visible scene so that surface which is bright in the visible scene appears dark in the corresponding IR scene. In some cases, this technique has been elaborated by using a color table for visual-to-IR conversion. This technique is obviously limited (an asphalt road and a lake could be rendered with the same IR gray shade), and cannot handle diurnal variations.

At the other end of the IR simulation spectrum are models which have very elaborate models of heat transfer, and which may include time-dependent shadows, specialized natural feature models, and angle-dependent surface emissivity and reflectivity. This complexity may be necessary when an accurate signature is required for a particular object or natural feature. However, these models are very complex to set up, and require a long time to generate a single image.

IR Simulation Methodologies

- **Simplest** - transform a visible image
 - complement visible color
 - color table
- **Most complex**
 - detailed thermal model with CFD for air flow, vegetative evaporation, etc.
 - time-dependent shadows
 - angle-dependent emissivity

IRGen Principles

- IR simulation intended for real-time simulation and training applications. Compatible with standard modeling and simulation software.
- Three-dimensional faceted data bases, including moving targets, structures, and terrain
- First-principles models of heat transfer, radiation, and atmospheric propagation
- Easy to use; user can control all the parameters of the materials, environment, and sensor

IRGen Principles (continued)

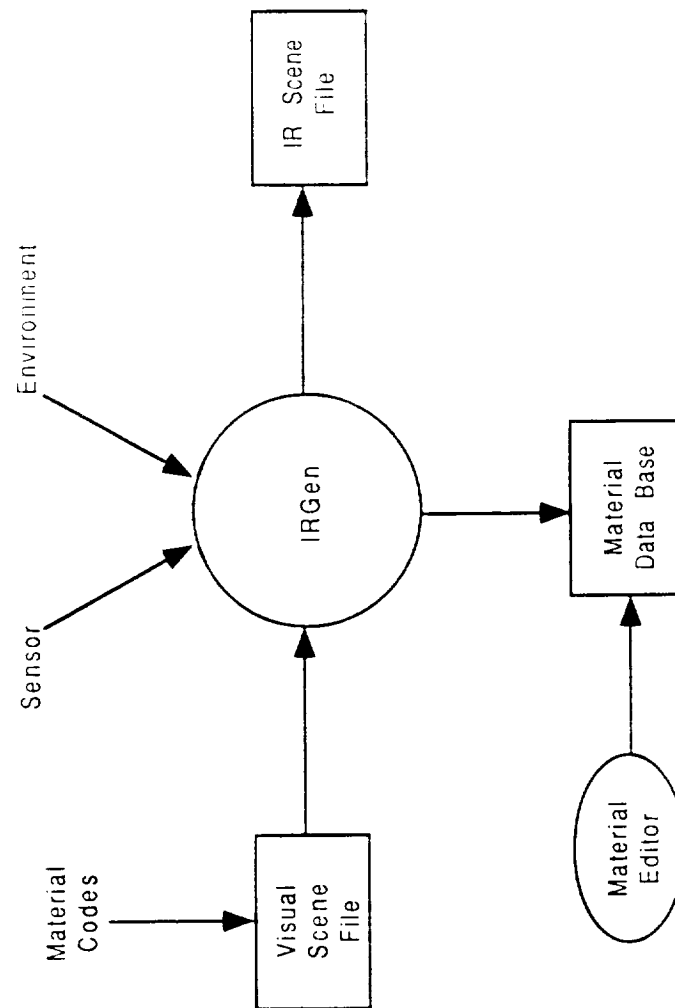
- **Built-in support for real-time graphics features**
 - **texturing**
 - **smooth shading**
- **Flexible and extendable**
 - **New materials can be created by the user**
 - **User-defined thermal models can be called by IRGen**
- **Reasonable setup and run time**

IRGen Data Diagram

This diagram shows the inputs and outputs of the IRGen program. The main input is a visual data base whose surfaces have been given material codes. Other inputs include the environment, atmospheric and sensor parameters.

The main outputs of IRGen is an IR data base whose geometry is identical to the visual data base geometry, but which has IR gray shades instead of the visual color. Other outputs include auxiliary graphics information such as texture maps and atmospheric attenuation information. The surface radiance and temperature values are accessible within the data base and are also recorded in a separate data file.

IRGEN DATA DIAGRAM



IRGen INPUTS

- **3-D visual data base from a data base creation program**
- **Each surface facet labeled with material code**
- **Environment**
 - **Thermal**
 - **Atmospheric**
- **Sensor characteristics**

IRGen OUTPUTS

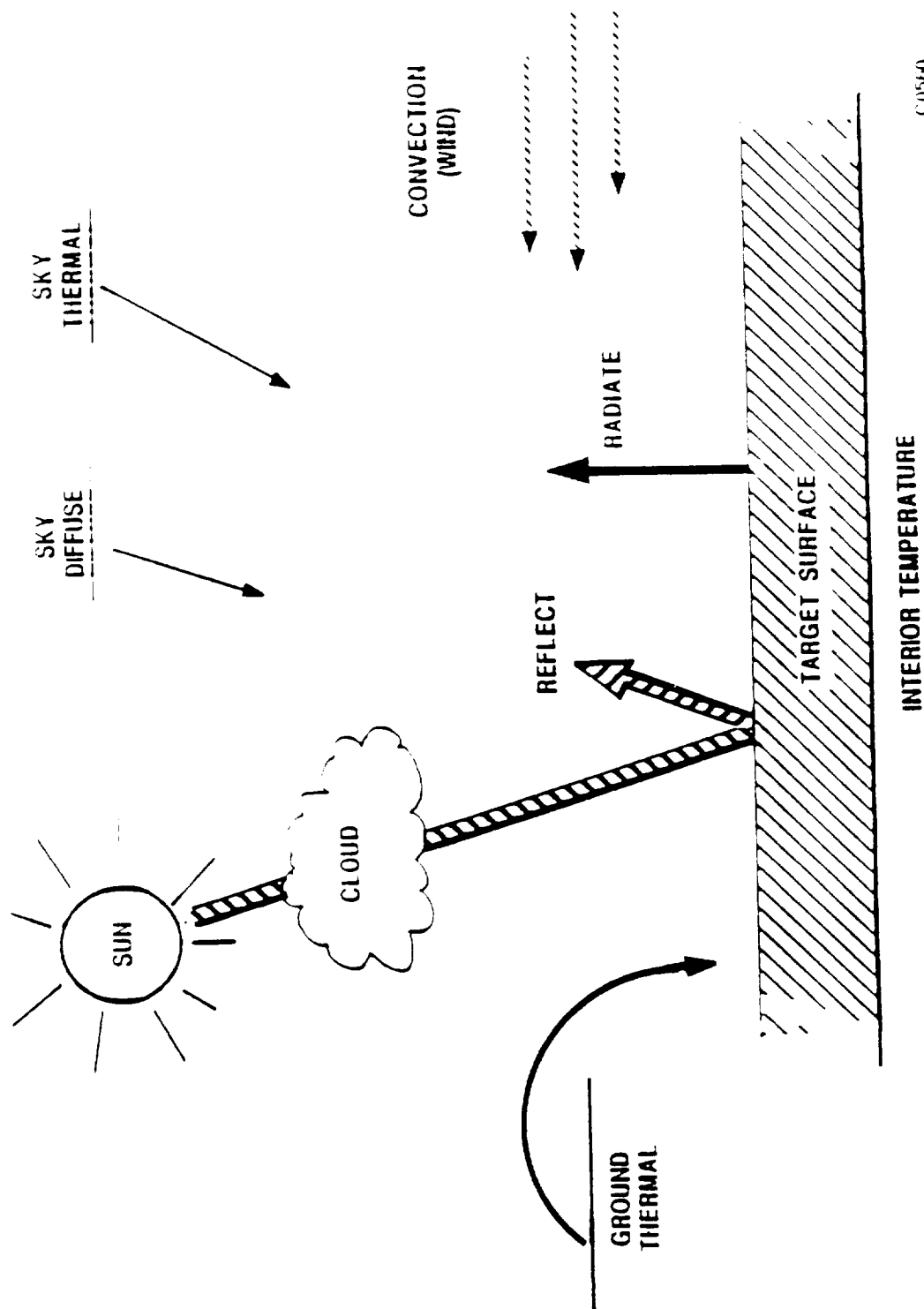
- 3-D IR data base with surface colors replaced by IR gray shades; radiance values stored as surface data
- Other real-time graphics data (attenuation, texture, etc.)
- Radiance data file

IRGen Thermal Model

This diagram shows the main sources of heat flux for the IRGen thermal model. Heat flow normal to the surface is simulated by integrating the one-dimensional heat transport equation, using a finite-difference method. External sources of heat flux include direct and diffuse solar radiation, sky and ground thermal radiation, and convection. Internal sources of heat flux include interior convection and conduction.

The surface radiance include both surface thermal emission, and reflected sky and ground radiance.

TSC THERMAL MODEL



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IRGen MODULES

- **Material Data Base**
 - **Surface and bulk thermal properties of scenario materials**
- **Thermal Model**
 - **Computation of surface temperature and radiance for every surface in the scenario**
 - **Integration of heat transport equation**
 - **External and internal heat flux sources**

IRGen MODULES (continued)

- **Environment Model**
 - **Solar, convective, sky, and ground heat sources**
- **Sensor Model**
 - **Sensor response function**
- **Atmospheric Model**
 - **LOWTRAN 7 (U.S. DoD standard model) integrated with graphics generator fog/haze function**

IRGen Operating Environment

IRGen currently generates data bases for both Silicon Graphics and Star Graphicon image generators. The latest version will run on any Silicon Graphics workstation.

Since IRGen requires a geometric data base, it must be used in conjunction with a geometric modeling program. The preferred modeling programs are MultiGen® and ModelGen™ (from Software Systems, San Jose, CA) which support the full set of image generator features such as level-of-detail, texture, and smooth shading. These modeling programs allow the user to enter a material code for each surface in a special data field that is reserved for IRGen.

An alternative version of IRGen runs with the AutoCAD® modeling program (Autodesk, Sausalito, CA).

IRGen OPERATING ENVIRONMENT

- **Hardware Platforms**
 - **Silicon Graphics (SGI) Workstation**
 - **Star Graphicon 2000**
- **Modeling Interface**
 - **MultiGen (SGI) modeling system - standard modeling system for real-time visual simulation. Supports level-of-detail, hierarchical data bases, texture.**
 - **AutoCAD (PC)**

IRGen Options

IRGen has several options for special applications. The Defense Mapping Agency (DMA) data option allows the use of the material codes provided by DMA digital feature analysis data (DFAD). With this option, the user does not have to enter any material codes. Note that DMA digital terrain elevation data (DTED) can be polygonized by MultiGen DTED option, and passed through IRGen into the IR data base.

The texture option allows the creation of IR textured data bases with thermally accurate texture maps. Textures are particularly important for realistic low-altitude flight simulation over terrain and water surfaces. The textures can come from three sources: (1) the visual data base, (2) a scanned IR image, or (3) statistical texture creation program.

The special effects option creates translucent and smooth-shaded surfaces.

IRGen OPTIONS

- U.S. Defense Mapping Agency (DMA) Data Interface
 - Digital Terrain Elevation Data (DTED) - can be polygonized by the MultiGen DTED Option
 - Digital Feature Analysis Data (DFAD) - automatically convert DFAD material codes and feature IDs to IRGen material codes.

IRGen OPTIONS (continued)

- **Texture**
 - **Generate thermally accurate textured surfaces.**
Important for terrain, sea, and cloud backgrounds
 - **Scanned images or synthetic textures**
- **Special Effects**
 - **Translucent surfaces (exhaust plumes, obscurants)**
 - **Vertex shading (temperature gradients)**

IRGen Material Data Base Parameters

Properties of IRGen materials are stored in the material data base, which is accessed by the material code. The user can modify material properties or add new materials. Material parameters 1 and 2 serve to identify the material. Parameters 3 through 17 are used for the temperature and radiance computations. ("Number of nodes" refers to the finite-difference method.) Parameters 18 through 20 are used to implement intersurface thermal coupling when computing smooth shading, and parameter 21 identifies the texture map for textured surfaces.

IRGen MATERIAL DATA BASE PARAMETERS

Identification:

1. material code
2. label

Thermal model parameters:

3. 3-5 micron emissivity
4. 8-12 micron emissivity
5. solar reflectivity
6. integration time increment
7. integration settling time
8. interior temperature
9. interior conductive/convective flag
10. interior thermal coupling
11. two-sided surface flag
12. shadow surface
13. number of nodes
14. node heat capacity array
15. node conductive transport array
16. node radiative transport array
17. node conductive coefficient array
18. node radiative coefficient array

Intersurface thermal coupling:

19. read/write flag for vertex thermal coupling
20. vertex coupling file number
21. vertex coupling flags

Textured materials:

22. name of thermal texture file